DEVELOPMENT OF A COMPUTER ORIENTED ALGORITHMIC APPROACH FOR OPENCAST MINE DISPATCH SYSTEM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

in

MINING ENGINEERING

By

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Rourkela-769 008

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CERTIFICATE

This is to certify that the thesis entitled, "**Development of a Computer Oriented Algorithmic Approach for Opencast Mine Dispatch System**" submitted by in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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ABSTRACT

Truck haulage is the most common means used for moving ore/waste in open-pit mining operations, but it is usually the most expensive unit operation in a truck shovel mining system. The state-of-the-art in computing technology has advanced to a point where there are several truck dispatching systems which offer the potential of improving truck-shovel productivity and subsequent savings. Introducing a dispatching system in a mine can achieve operational gains by reducing waiting times and obtain other benefits through better monitoring, optimal routing and grade control. Efficiency of the employed truck-shovel fleet depends on the dispatching strategy in use, the complexity of the truck-shovel system and a variety of other variables. It is a common situation in mining that considerable analysis of the available strategies is undertaken before dispatching is adopted. In most cases, computer simulation is the most applicable and effective method of comparing the alternative dispatching strategies.

To develop a computer based algorithm for despatch systems in open cast mines, the program asks the user to enter the number of trucks initially assigned to each shovel site. Experiments are made to investigate the effects of several factors including the dispatching rules, the number of trucks operating, the number of shovels operates, the variability in truck loading, hauling and return times, the distance between shovels and dump site, and availability of shovel and truck resources. The breakdown of shovel and trucks are modeled using exponential distribution. Three performance measures are selected as truck production, overall shovel utilization and overall truck utilizations. But, the main factors affecting the performances are the number of trucks, the number of shovels, the distance between the shovels and dump site, finally the availability of shovel and truck resources. Also, there are significant interaction effects between these main factors.

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SYMBOLS

TP	Total Production
SU	Shovel Utilization
TU	Truck Utilization
DR	Dispatching Rule
NT	Number of Operating Trucks
S	Number of Operating Shovels
LT	Truck Loading Time
HT	Truck Hauling Time
RT	Truck Returning Time
SDD	Distance between Shovels and Dumping Point
A	Shovel and Truck Availability
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
FTA	Fixed Truck Assignment
MSPR	Minimizing Shovel Production Requirement

MTWT	Minimizing Truck Waiting Time
MSWT	Minimizing Shovel Waiting Time
MTCT	Minimizing Truck Cycle Time
MSC	Minimizing Shovel Coverage
ELS	Earliest Loading Shovel
LWS	Longest Waiting Shovel
AR	Adaptive Rule
K	Shovel Number to Which Truck is Assigned
TNOW	Time Elapsed from Start of Shift
TSHIFT	Total Shift Time
Pi	Actual Shovel Production at Current Time
POi	Shovel Target Production
SRi	Ready Time of Shovel for Loading This Truck
TRi	Ready Time for the Truck to Be Loaded by the Shovel
TCT	Truck Cycle Time
TT	Mean Truck Travel Time from Dispatching Point to Shovel
STU	Standardized Truck Utilization
TU_{cur}	Current Truck Utilization
TU_{mean}	Mean Truck Utilization
SDTU	Standard Deviation of Truck Utilization
SSU	Standardized Shovel Utilization
SU_{cur}	Current Shovel Utilization
SU_{mean}	Mean Shovel Utilization
SDSU	Standard Deviation of Shovel Utilization

CHAPTER I

INTRODUCTION

Surface mining involves the basic procedures of topsoil removal, drilling and blasting, ore and waste loading, hauling and dumping and various other auxiliary operations. Loading of ore and waste is carried out simultaneously at several different locations in the pit and often in several different pits. Shovels and frond-end loaders of various sizes are used to load material onto trucks. Hauling material from the shovel production faces to the dumping sites must be accomplished through a network of haul roads of various length and grades. Haul roads can be extremely complex, cover large surface areas and pass through extreme elevation changes. Loading times of shovels depends on shovel capacity, digging conditions, and the truck capacity. Queues often will form at the shovels since trucks of various sizes may be used at individual shovels. Thus, allocation of trucks to haul specific material from a specific pit or shovel becomes a complex problem. Obviously, efficient mining operations are strongly dependent on proper allocation of trucks to shovels and the respective allocation of trucks along the appropriate haul roads and dump sites. The number and type of trucks and shovels are two important factors in determining the optimum design parameters of an open-pit mining system. Also, the characteristics of truck's arrival and loading times at shovels determine the performance measures (i.e. total production) of truck-shovel system. The assumptions of identical truck travel and loading times may result in underestimating or overestimating the performance of these systems.

The ability to assess the performance of a truck-shovel system in open-pit mines accurately would be a very useful device for mining companies. Any marginal improvement in the performance would save a significant amount of money in most modern open-pit mining operations where very large capital investments are required to purchase and replace the necessary equipment. Accurate assessment of the system performance is not so easy because of the complexity of the system. However, with some simplifying assumptions one can obtain fairly accurate results using computer simulation techniques for all practical purposes. One of the major issues in open-pit mining operations is the selection of trucks and shovels that would satisfy some economic and technical criteria optimally. This problem is faced at the design stage of the mine as well as during the operation of the mine where there may be a need to redesign for expansion purposes. The solution lies in efficient prediction of performance parameters for various combinations of trucks and shovels under realistic assumptions. These parameters could be used to determine the impact of different scenarios on the productivity of the operation and select the best promising alternative for actual design goals. Given the characteristics of the truck-fleet, dynamic routing of trucks to different service areas (i.e. loading and dumping) cannot be done arbitrarily since this would seriously affect the productivity of the mine. Therefore, it is very important for optimal operation that the design parameters should be determined accurately and applied at all stages of mining operation. Efficient truck dispatching represents a traditional approach to improve production equipment utilization in open-pit mining operations. Increasing the equipment utilization can result in a greater increase in the profitability of operation and decrease in the truck-fleet size as well as increase in production. Truck haulage represents 50% or more of the total operating costs in most surface mines and efforts have been made to reduce these high haulage costs. These include improving operating performance of the trucks resulting in higher efficiency and reliability, increasing the payload capacity of trucks, employing in-pit crushers and conveying systems with truck haulage, and using trolley-assisted trucks to reduce the truck cycle times. Another concept currently under development is the use of driver-less trucks since this approach has the potential to reduce the labor costs. These efforts have focused on truck or haulage system designs. The same cost reduction goals can also be realized by more efficient utilization of trucks and shovel resources, which is primary objective of computer-based truck dispatching systems. With computer-based truck dispatching, one hopes either to increase production with existing truck and shovel resources or meet the desired production goals with reduced equipment requirements. This goal is achieved with careful consideration of assignment decisions that increase utilization of truck and shovel resources and reduce waiting times in the haulage network. Haulers are only productive when they are carrying a load and loaders are also only productive when loading material for haulage. Idle equipment times are the essence of non-productive equipment and they have to be minimized.

Truck dispatching issue is one of assigning trucks to shovels in a well designed system on real-time basis so as to ensure the achievements of some goals or minimize the underachievement of such goals. The general problem solved by truck dispatching routines is to determine the shovel to which the current truck at the dispatching station should be assigned. The objective of computer-based truck dispatching is to improve the equipment utilization and increasing production subject to a variety of practical constrains. A computer truck dispatching system consists of two main components as hardware and software. Developments in hardware are concentrated on signal acquisition and transmission equipment and computer. Computational procedures are becoming relatively easier with the development of high-speed computers. Also, truck dispatching software presents many opportunities for improving the performance of open-pit mining systems.

Truck-shovel system is a complex mining system with respect to its stochastic features and interaction between system elements. It is naturally impossible to derive some global optimal solution algorithm for truck dispatching problem. Therefore, every dispatching criterion is based on a consideration of local optimization. Various methods have been employed to model truck-shovel system. Some of these methods rely on empirical rules or trial and error and some are highly mathematical requiring significant computational effort.

Chapter II
LITERATURE REVIEW

2.1 Problem Statement

The purpose of this project is to develop a truck dispatching program for a medium-sized open pit mine consisting of several production faces and a single dump location. The main objective of this project is to enhance the analysis and comparison of truck dispatching policies and search for a rule applicable to open pit mines.

<u>The specific objectives are to:</u>

1. Study the impact of various dispatching systems;
2. Test and compare several heuristic dispatching strategies for improving haulage productivity;
3. Serve as a planning tool for estimating the expected production of a given truck haulage system;
4. Reveal bottlenecks in a proposed truck haulage system;

2.2 Truck dispatching systems

The significant improvements in computer technology have led the mining industry to develop several decision making models for deciding the best possible assignment of trucks in an open-pit mine. Computerized truck dispatching systems were developed in the late 1970`s and have become the common mode of operation at many large open pit mines. But, they were not economically justified for small and medium-sized haulage operations due to high costs of implementation. Fortunately, tremendous improvements in computer hardware and decreases in costs occurred since late 1980`s as well as the need for to increase productivity and equipment utilization. Truck dispatching systems can be classified into three major categories as: manual, semi-automated and full automated. Most of the dispatching systems in the literature are either semi-automated or full automated. The benefits and shortcomings of the dispatching systems are outlined in the following sections.

2.2.1 Manual Dispatching systems

The manual dispatching system is the standard practice of truck assignment. The trucks are assigned to a particular shovel and dump point at the beginning of the shift, changing the circuit according to the dispatcher’s best judgment of the situation based on production requirements, shovel locations, fleet availability, etc. In this system, the decision making requires a dispatcher located at a strategic point in the pit to oversee the operation and kept tract of the equipment status and location. The effectiveness of the system relies heavily on the use of radio-transmitted information and therefore both shovels and trucks are equipped with two-way radio to allow communication. The system has been used in open-pit mining operations since the early 1960`s and it is recommended for small mines having, say up to 10 operating trucks.

Mueller described a manual system based on a dispatch board which can be used as an analog computer. The objective of the board is to aid the dispatcher in keeping track of the status and position of the equipment in the pit and guide his decision making process. The main components of the board are trucks and shovels represented by blocks. The decision for dispatching is taken after the truck has dumped its load at which point the operator communicate with the dispatcher. The dispatcher then adjusts the board to correlate with the equipment in the pit in order to make the proper assignment. The dispatcher has to rely on his personal judgment and professional experience in a particular pit.

2.2.2 Semi-Automated Dispatching Systems

In a semi-automated system, the computer is programmed to aid the dispatcher in the decision making process for assigning the trucks. A digital computer is used to record the status of equipment and the location of trucks which make up the haulage fleet. The computer is also used to assist the dispatcher to assign the trucks to shovels according to the dispatching strategy applied. The system is called semi-automated since the computer does not have direct contact with the equipment and the dispatcher is necessary to communicate all instructions. The dispatcher correlates this information with the actual position of equipment in the pit and takes an independent decision which may or may not agree with the computer suggested assignment. The dispatcher relays information manually by radio or visually.

The main advantage of this dispatching system is that it facilitates recording of events, generating production reports and reduction of equipment waiting times. Using this system, the maximum achievable production will be a function of the dispatching policy applied. Therefore, the models developed for semi-automated systems must be as flexible as possible to allow changes in operating policies according to the prevailing conditions at any particular time.

This system is applicable to medium-sized mines, say up to 20 operating trucks. Hodson and Barker described the implementation of semi-automated dispatching system and the upgrading of a passive system which only records information to the one where computer suggests the optimal truck assignment. The assignments are based on a two step process. In the first step, each shovel is guaranteed a certain number of trucks. In the second step, the distribution of the trucks within a sub-system represented by dumps is regulated according to the shovel loading time. The dispatcher has complete control of the operation. Dispatching is done on the basis of determining an optimum cost per ton/match factor relationship for various cycle times. As soon as the truck driver requests an assignment, the computer calculates the match factor of a particular shovel in that dump’s sub-system. When this is within a pre-specified optimum range, the trucks remain in that sub-system, and the truck is subsequently dispatched by the computer to the best available shovel. If the chosen sub-system has more trucks than required, the computer tests other sub-systems and reassigns the truck to the sub-system which has less than the required number of trucks. To control the distribution of trucks in each sub-system, the second step is used. This is done because the trucks are dispatched based on an average system match factor. In this strategy, the trucks do not change routes very often since at the beginning of shift, the dispatcher matches the trucks and shovels.

2.2.3 Automated Dispatching Systems

The fundamental problem with both manual and semi-automated dispatching systems is the limited ability of human dispatcher to store and transfer large amount of information over a long time span in a very short processing time. This was the main reason for the development of full automatic dispatching systems and they are the most emphasized in current literature. Automated dispatching systems enable the computer to make the necessary decisions for dispatching trucks without any intervention by a human dispatcher. Truck locations are detected by sensors (i.e. signpost beacons) and sent to the computer, which calculate the destination for truck allocations using the chosen dispatching strategy applied as in semi-automated dispatching systems. The assignments are sent to trucks directly and appear on LCD displays mounted in truck’s cabin or in a central location where trucks go by.

The advantage of such systems is that the dispatcher does no longer need to communicate instructions to the trucks or to keep track of the truck status. Automated dispatching systems have been reported to decrease truck haulage requirements from 5 to 35 percent. The benefits vary depending on type of material handling fleet, haulage network configuration and specific dispatching procedures. They provide precise and timely production reports and increase efficiency of the haulage equipments. The only drawback with this system is the high installation cost involved due to monitoring and transmission equipments required. Himebaugh described an automated dispatching system called "DISPATCH", developed and marketed by Modular Mining Systems Inc., which aims to maximize productivity with available equipment or achieve a desired production with minimum equipment. Dispatching trucks to meet either of these objectives is a dynamic operation which requires continuous monitoring of route selection and shovel and truck status and location to determine optimal truck assignments. DISPATCH is the best known and most documented large-scale, computer-based, mine management system which controls truck-shovel operations at an open-pit mine. This is one of the most successful and powerful systems and is in use at many open-pit mines worldwide. The system was developed based on a real-time computer program and consists of two separate functions which allow communication between each other through a common data base. The system software is modular in design. In the first part, real-time operations are handled.

The dispatcher's log is maintained in the second part of the program. This model can be used for both assisted and direct computer dispatch. The system accounts for shovel moves, shovel breakdowns, shovel digging changes, dump and crusher downtime, and changes in material types. The dispatcher basically manages the whole operation by simple monitoring of assignments supplied by the computer.

The truck driver requests an assignment at the beginning of the shift and the system indicates when the truck arrives at the shovel and when it is loaded. The shovel operators provide information on the type of material being loaded, delay or breakdowns. DISPATCH assigns trucks to minimize queuing of trucks at shovels and to minimize shovel idle times using dynamic programming assignment logic.

Current truck locations, speed factors and status, shovel digging rates, locations and status are all considered when determining truck assignments. DISPATCH tracks the location of trucks using data gathered from location beacons or from information entered into field control units by truck drivers. The productivity improvements of 10-15 % have been reported at mines using DISPATCH program.

2.3 Truck Dispatching Simulation Models

A number of computer models have been developed for truck dispatching systems. In a study by Cross and Williamson, the effect of dispatching on fleet requirements was analyzed. The advantages of increasing the size of shovel were also studied. They compared a truck haulage system in the dispatching mode and non-dispatching mode. In the dispatching mode, trucks are assigned to the shovel which has been idle longest or would be idle next. In all studied cases, the dispatched system with one less truck hauled same tonnage as the non-dispatched system. The results of simulation have shown that the rate of production increase tended to decrease as the number of trucks operating increased. The study also pointed out that dispatching truck in open-pit mines tends to increase production by taking advantage of the irregularities within the system. There is more control over the operations and that reduces the disorder and improves the efficiency of the system. It was concluded that by using dispatching it is possible to reduce the number of operating trucks required for a specific production level, and the operating cost of the haulage is the most critical factor in any decision on the size and number of equipment of a particular operation. Brake and Chatterjee developed an interactive stochastic simulation model consisting of two interconnected modules. They used the SIMULA modeling package and compared three different dispatching policies namely, fixed allocation, minimizing queuing at dumps and minimizing overall queuing. In the mine planning module, the cycle time elements for truck/shovel operation were calculated and the module allowed only lognormal distribution for all stochastic events. The model made dispatching decisions after dumping operation and simulated equipment breakdowns. The model predicted production and utilization increases of around 3-4 % for both shovels and trucks. The relatively small improvements were due to the size of the equipment fleet. It was concluded that greater improvements in productivity ant utilization would be realized over longer haul distances than over shorter distances. The other module, mine evaluation module, was used to evaluate mines already in production and required actual observed times for all load, haul and dump events.

The simulation model described by Kim and Ibarra was designed to study the effect of dispatching on productivity over a conventional mode of dispatching, i.e. fixed. The model used the minimum shovel waiting time strategy as the decision making criterion to assign the trucks to shovels. For analysis purposes, the input data were obtained from a real system and then adjusted and validated by comparing the results with a non-dispatching strategy. The model considered the characteristics of the haulage network, speed limits, right of way rules, equipment performances and availabilities, etc. Each route has a common intersection and it is compulsory for all trucks to pass through this point. This common intersection is used as the dispatch point where actual truck assignments are made. The results of this study indicated that dispatching increases truck/shovel productivity nearly 10 %, and also leads to a reduction of more than 30 % in truck and shovel idle times. A further conclusion was that dispatching yields greater improvements for combination of short and long haul roads.

The model described by Wilke and Heck was developed to study the existing methods of dispatching policies taking into consideration the equipment performance and the occurrence of equipment breakdowns during the shift. They recognized the importance of blending requirements as well as maximizing the fleet utilization. The model is based on a stochastic simulation and is divided into two parts. The first part of the model is used to simulate the equipment performance taking into account various truck speeds in different haul roads, different truck types, the haulage profile, and possible queuing at shovels and dumps. The second part is completely independent of the first part and is used to determine the probability of occurrence of breakdowns and their duration. The dispatching policy was to initially allocate trucks to shovels according to the production requirement and then assign empty trucks to shovels which are most behind their schedule, taking into account trucks which are already on their way. Tu and Hucka developed a stochastic simulation model to analyze the performance of a truck/shovel operation considering various haulage networks and the effect of dispatching policies on productivity. The model is very flexible as it allows a choice of a number of different dispatching policies, namely fixed, maximizing shovel utilization and maximizing truck utilization. They used SLAM simulation language, which allows representing each truck and shoveling as an entity moving through a discrete event network. Shovels are also modeled as resources amenable to seizure when breakdowns and face moves occur. The model was validated by a comparison between the simulation results and actual production statistics. This study concluded that the use of dispatching systems in an open-pit mine can save at least one operating truck per shift, or 2-3 % of the total truck fleet. The study also showed that computerize dispatching is more effective when shovels are under trucked. When shovels are over trucked, the addition of a shovel results in a greater increase in production than that from computerized truck dispatching alone. Billette and Seka developed a simulation model to assess the best assignment for the trucks and to determine the additional cost involved in blending operations. They claimed that the actual mining operation's efficiency is related to the financial efficiency. An attempt is made precisely to define the efficiency parameters involved. A production figure is obtained by simulating the operation on the basis of fixed assignment. These values were then compared with the values derived from analytical methods. The input data were obtained by using deterministic models to derive average values which were then fitted to weibull distribution. The parameters of this distribution were determined from past experience or from published literature. The results showed that for operation with small number of trucks, analytical method tended to underestimate the production compared to simulation model.

Lizotte and Bonates described a stochastic simulation program used to assess several dispatching rules applicable to small scale computerized systems for optimizing truck/shovel productivity. They tested the maximize shovel utilization, maximize truck utilization and shovel coverage strategies using their weibull-based simulation model to assess the potential improvements in productivity. The model does not consider any real particularities such as equipment breakdowns, scheduled breaks, shovel moves, etc. and single truck type was considered. The simulation program was structured on an advance clock approach which enabled the insertion of dispatching rules at various point in the haulage network and was written in FORTRAN. Elbrond and Soumis presented an integrated production planning and truck dispatching procedure using mathematical optimization algorithms. For real-time dispatching, they proposed an assignment algorithm which minimizes the sum of squared deviation of the estimated truck waiting times from those of the operational plan for the current truck at dispatching point and the next 10-15 truck which will require assignment sooner. To test the dispatching strategy, they developed a simulation model. The model generates activity times according to Erlang distributions with mean and standard deviation corresponding to observed values. Simulation results predicted the gain in production of 3 % and reduction of 12 % in truck waiting times.

In the study carried out by Tan , a simulation model using the SIMAN simulation language was developed to investigate a number of heuristic dispatching strategies on hypothetical mine data with varying number of trucks and distances between dispatch point and shovels. The study assumed a single dispatch point, identical trucks and identical shovels. Normal distribution was used for all event components. The results from the simulation runs showed that many dispatching criteria have good potential to increase the productivity but none of the basic heuristic dispatching rules can dominate all others. Some of the rules were performing better than other such as minimizing truck waiting time, minimizing truck saturation. He suggested searching for a hybrid dispatching strategy. He also suggested several modified heuristic strategies like SIMAN and CINEMA PC-based simulation model to simulate and animate truck-shovel operations of surface mines. The model is capable of simulating six dispatching strategies, which are minimize truck wait time (MTWT), minimize shovel wait time (MSWT), minimize shovel production requirement (MSPR), minimize truck cycle time (MTCT), minimize shovel saturation (MSC), and fixed truck assignment (FTA). He has also evaluated a mathematical dispatching strategy called DISPATCH using linear and dynamic programming. The model is an efficient planning tool for choosing optimal fleets.

Forsman and Vegenas developed a stochastic simulation model called METAFORA for determination and evaluation of dispatching strategies for operating loader/truck systems in mining. The model combines simulation and graphical animation with computer aided design. Two sizes of loaders and trucks can be used simultaneously. Three dispatching rules, (fixed, maximize loaders and maximize trucks) are modeled to simulate for evaluating alternative dispatch strategies. The simulation results indicated that maximize trucks rule performed better than others since truck waiting times at loading points are reduced.

There were six heuristic truck dispatching alternative rules in the model. According to the different criteria, system simulation experiments were carried out under various mine conditions. The output of the simulation included the utilization of shovels and trucks, total coal and waste productions, and productions from each shovels. A comprehensive analysis and comparison of different dispatching criteria were made and the applicable ranges of each criterion under various operating number of trucks to shovel ratios were defined as a comprehensive dispatching criterion. Finally, a combined optimal dispatching criterion was implemented.

All components of the haulage system were represented by graphical modules. The model was run in both dispatching and non-dispatching modes with different fleet sizes in order to optimize the number of trucks in the system. Simulation results showed that the dispatching system is generally more productive than the non-dispatching mode. This improvement was significant in fleet sizes around the optimum. However, when the system is either under-trucked or over-trucked, the influence of the dispatching was not significant. Kolonja developed a stochastic simulation model for an open-pit transportation system to study the effect of a new in-pit crushing system on the productivity of a truck and shovel operation. The model is programmed in GPSS/H simulation language and animated with PROOF software to validate since it is designed for a new system. The model can be used to estimate production for various trucks and shovels configurations as a planning tool. The fixed truck assignment policy is applied as the operating dispatching strategy. The model determines the optimum number of trucks for various system configurations without considering mismatch. Economic analysis is done to evaluate two different transportation systems (i.e. truck haulage with and without in-pit crushing system). Simulation results showed that the truck haulage with in-pit crushing system is 50 % more costly than the truck haulage without in-pit crushing system.

CHAPTER III

TRUCK DISPATCHING HEURISTICS

3.1 Overview of Heuristics

Computerized truck dispatching systems require a procedure for assigning trucks to shovels in an open-pit truck/shovel haulage system. Each computerized system developed should employ a unique policy. In order to maximize fleet efficiencies, several methods ranging from simple heuristics to complex mathematical procedures can be applied in this decision-making process. The objective of any truck dispatching procedure is to increase the productivity of the system with the given fleet of trucks and shovels or a significant reduction in the number of trucks and shovels needed for a given production target subject to a variety of practical constraints. Reduction in truck and shovel waiting times contribute much to these goals. Dispatching policies consider different objectives in varying degrees of sophistication. For the heuristic rule-based dispatching systems, usually the dispatching decisions are taken when the truck reaches the dump site. They invoke a chosen heuristic rule; say minimizing truck waiting time, at the time of making a dispatching decision. The computer then checks the current status of the equipment in the mine and dispatches the trucks to the most appropriate shovel at that instant. The most appropriate shovel is determined as a function of the dispatching policy applied.

A heuristic procedure or algorithm can be defined as a relatively simple formula or procedure applied to solve a problem. In mathematical terms, heuristic algorithm in most cases can solve a problem, but cannot guarantee an optimal solution. In general, heuristic procedures consider only current objectives without consideration of future events or long-term planning goals. Often, the solutions of heuristic procedures are based on local (i.e. individual elements and short time) optimization. The dispatching algorithms based on heuristic rules are easier to implement and do not require much computation when making dispatching decisions in real-time. Typically, all heuristic rules are applied one-truck-at-a-time.

That is, current truck assignment decision is made with indifference to the assignment of other trucks that will be made in the near future. Also, most heuristic rules ignore essential constraints or secondary goals of system operation such as maintaining product grade requirements by balancing production ratios among available loading sites.

In this study, the existing truck dispatching criteria currently available are reviewed and their definitions, primary considerations and basic characteristics are presented. The basic rules can be grouped into three categories as: criteria originated from consideration of optimizing equipment idle time measurements, criteria originated from maximizing truck productivity, and criteria originated from the optimization of the shovel production requirements. In the following sections, the basic rules that are modeled in this study are explained.

3.2 Fixed Truck Assignment (FTA)

In this strategy, each truck is assigned to a particular shovel and dump point at the beginning of the shift and remains in the same circuit for the entire duration of the shift. The number of trucks that are assigned to a particular shovel is a function of the performance variables of the shovel under question, the desired production level from that shovel, and the expected travel and waiting times for the trucks in the haulage network. There is no changing of assignment during the operation (i.e. locked-in dispatching). Only in the event of a change in the operational conditions such as shovel breakdowns, trucks are reassigned. Due to stochastic nature of haulage operations and random occurrence of down times, formation of long queues at a specific shovel occurs with some frequency.

This strategy has been proven to be the most inefficient. This is mainly due to the fact that the equipment does not operate at constant rate. The reason for this is due to the variation of event times, along with the interactions between trucks at the road intersection points. Furthermore, both trucks and shovels are down for maintenance and servicing. The shovels may sometimes be required to move to new locations during the shift and unpredicted breakdowns may also occur. Under this policy, it is very common to find several trucks waiting in queue at one shovel for loading while another shovel may have been idle for a long time due to the unavailability of trucks. The highest productivity that this system can achieve is when all shovels operate continuously. If one truck is being loaded, the other trucks in the same circuit are either traveling empty or loaded, or are in the process of dumping. This implies efficient operation of the system when trucks are evenly formulated. The study concluded that the comprehensive dispatching criterion took advantage of different criteria and the effect was distinctly better than using a single dispatching rule under various mining conditions. Temeng presented a real-time truck dispatching process using a transportation algorithm to implement production maximization and quality control goals. The assignment of trucks is based on the solution to a non-preemptive goal programming model, which determines optimal route production rates and serves as a basis for selecting needy shovels. In the real-time dispatching process, needy shovels are determined by minimizing the deviation of the cumulative production of each route from its targets. Trucks are assigned to needy shovels by a transportation model that minimizes the total waiting time of shovels and trucks. The results showed significant increase in production over fixed dispatching and ensured quality control Ataeepour and Baafi developed a stochastic

simulation model to analyze the performance of a truck/shovel operation using the Arena software. Arena uses graphical modeling approach as well as animation notion. Systems are typically modeled in Arena using a process orientation. Arena model consists of a graphical representation of the processes where entities (i.e. trucks) move as they progress through the system. They described the main elements of Arena required to perform a truck/shovel simulation and to view the simulation results by means of animation. The layout of the haulage system consisting of five shovels in production faces and three dump sites was generated using the draw tool in Arena. It is assumed that the required number of trucks is always available.
However, the system often suffers from a lack of trucks due to the high costs involved. The choice of fixed truck assignment strategy may be the result of the evaluation of the operating performance data, such as shovel load and delay times, truck cycle and wait times, production targets, equipment utilizations, etc. This strategy can serve as a baseline by which the effectiveness of other heuristic rules can be measured and it can also be used to validate the simulation model.

3.3 Minimizing Shovel Production Requirement (MSPR)

The objective of this criterion is to achieve the shovel target production, which has been optimized by linear programming or other approaches. When shovels have production targets, a simple heuristic rule is to assign the empty truck at the dispatching point to the shovel which is most behind in its production schedule, taking into account the total capacity of the trucks en route. This rule is most suitable for mines having quality control objectives such as blending requirements. Tan and Ramani used the following formula for identifying the most lagging shovel.

$$k: \operatorname{argmax} \{(TNOW * PO_i / TSHIFT)\ P_i\}, \qquad (3.1)$$

where k: shovel to which the truck is to be assigned

TNOW: time elapsed from the start of the shift

TSHIFT: total shift time (i.e. 480 minutes)

P_i: actual shovel production at current time

PO_i: shovel target production

The criterion used by Kolonja is the same, except that actual shovel production explicitly includes capacity of all trucks en route in addition to the trucks already being loaded. In this study, the approach suggested by Kolonja is used. It can be seen from the formula that the random features of the network are not taken into consideration and thus the productivity of the system can be improved very slightly. Also, it must be pointed out that several trucks in succession might be sent to the same shovel that is lagging in production due to a breakdown earlier in the shift. This would cause trucks to be queued up at the shovel in question while others may stay idle. Of course, this might be desired if a given target production from each shovel is strictly compulsory on a shift basis for blending purposes. However, this would result in total system production being sacrificed significantly. Tan claimed that this criterion can guarantee the global optimal solution given by linear programming if the stochastic features of the system can be ignored. Unfortunately, such random impacts are significant in mining operations and cannot be ignored. To explain this basic heuristic dispatching rule, a simple two shovel example is presented in Table 3.1. It is assumed that one of the shovels is faster than the other and their average loading times are 2 and 3 minutes, respectively. Also, the duration of shift is assumed as 480 minutes. The target production levels for the shovels are expected to be 160 and 240 truck loads, respectively in a shift. Initial truck assignments for the shovels are made at the start of the shift arbitrarily, as 3 and 4 trucks, respectively. If the difference, (B-A), is equal to each other for the two shovels, the truck assignment is made to shovel 1 or shovel 2 arbitrarily.

3.4 Minimizing Truck Waiting Time (MTWT)

In this criterion, an empty truck at the dispatching point is assigned to the shovel which will result in the least truck waiting time for the truck to be loaded by the shovel. The objective of this criterion is to maximize the utilization of both truck and shovels. However, when the number of trucks in the system is relatively small and the trucks do not wait at shovel very often; this rule may result in underutilization of some shovels and, consequently, shovel idle times since several shovels may have zero truck waiting times at the same time. Secondary tiebreaking rules may be necessary for dispatching the trucks and these rules may dominate the overall dispatching decisions. This policy is recommended in mines where specific shovel production targets and grade requirements do not exist. The decision-making criterion is as follows:

$$k: \arg\min_i \{\max\{ SR_i - TR_i\},0\}\}, \qquad (3.2)$$

where

k: Shovel number to which the truck is assigned

SR_i: Ready time of shovel for loading this truck

TR_i: Ready time for the truck to be loaded by the shovel

It should be noted that if (SRi - TRi) is greater than zero, then it corresponds to the truck waiting time at shovel i. Truck ready time, (TRi), is defined as the predicted truck travel time from dispatching point to the shovel and it is determined from the summation of current time, (TNOW), and average truck travel time from the dispatching point to the shovel. Shovel ready time, (SRi), is defined as the predicted ending time for the shovel to complete loading all the trucks in the queue at shovel including the one being loaded and those that are en-route to this shovel, but have not reached yet. Thus, the arrival times of truck on the road should be determined for each shovel. Using these arrival times, a Gantt chart can be constructed for each shovel, which will provide the best estimated shovel ready times for a new truck at the dispatching point. Shovel ready times need to be updated whenever the truck reaches the dispatching point, arrives at or leaves a shovel after loading. Since actual times are unknown at the time of making a dispatching decision, the real-time data recorded should be used for events that are already happened. For the future events, average values should be used to update the shovel Gantt charts (see, Fig. 3.1).

Table 3.1 An Example Problem for Minimizing Shovel Production Requirement Rule (MSPR)

No.	Arrival time at the dispatch system TNOW(min)	Target production SIP (loads)		Production Current Time SIP (loads)		No. of trucks on routes TP (loads)		Total production A=SP+TP (loads)		B=[(TNOW*SIP) /(TSHIFT)] (loads)		Difference B-A (loads)		Shovel assigned K max(B-A)	
		S_1*	S_2*	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
1	00	240	160	0	0	1	3	4	3	-	-	-	-	-	-
2	10	240	160	2	1	2	2	4	3	5	3	1	0	1	-
3	12	240	160	3	2	2	1	5	3	6	4	1	1	1or2	1or2
4	100	240	160	45	28	3	2	48	30	50	33	2	3	-	2
5	102	240	160	45	28	3	3	48	31	51	34	3	3	1or2	1or2
6	200	240	160	93	60	2	2	95	62	100	66	5	4	1	-
7	202	240	160	93	60	3	2	96	62	1001	67	5	5	1or2	1or2
8	300	240	160	146	92	1	3	147	95	150	100	3	5	-	2

*S_1 and *S_2 are the Shovels.

The solution to the same example with two shovels (but with different dispatching times) is provided in Table 3.2. Here it is further assumed that the two shovels are separated from each other by a distance of one minute. The mean travel times from the dispatching point to the shovels are 5 and 6 minutes, respectively and the return times from the shovels to the dispatching point are 6 and 7 minutes, respectively.

When trucks arrive at the shovel, one of two situations may occur: the shovel is idle, hence it starts to load a truck for say 2 minutes on the average, or it is busy causing trucks to wait in queue. If shovel is idle, there is no waiting time for a truck and the shovel immediately loads it. But, if the shovel is busy, the truck waits until it becomes idle. Moreover, all trucks arriving at the shovel enter the queue and await their turn at the shovel. When waiting time is zero, it means that the truck has positioned it and is ready to be loaded at the same time the shovel finished loading the previous truck. Positive waiting times mean that the truck arrived at the shovel, which is still loading another truck. There may or may not be other trucks in the queue. It actually shows the waiting time of the shovel for a truck.

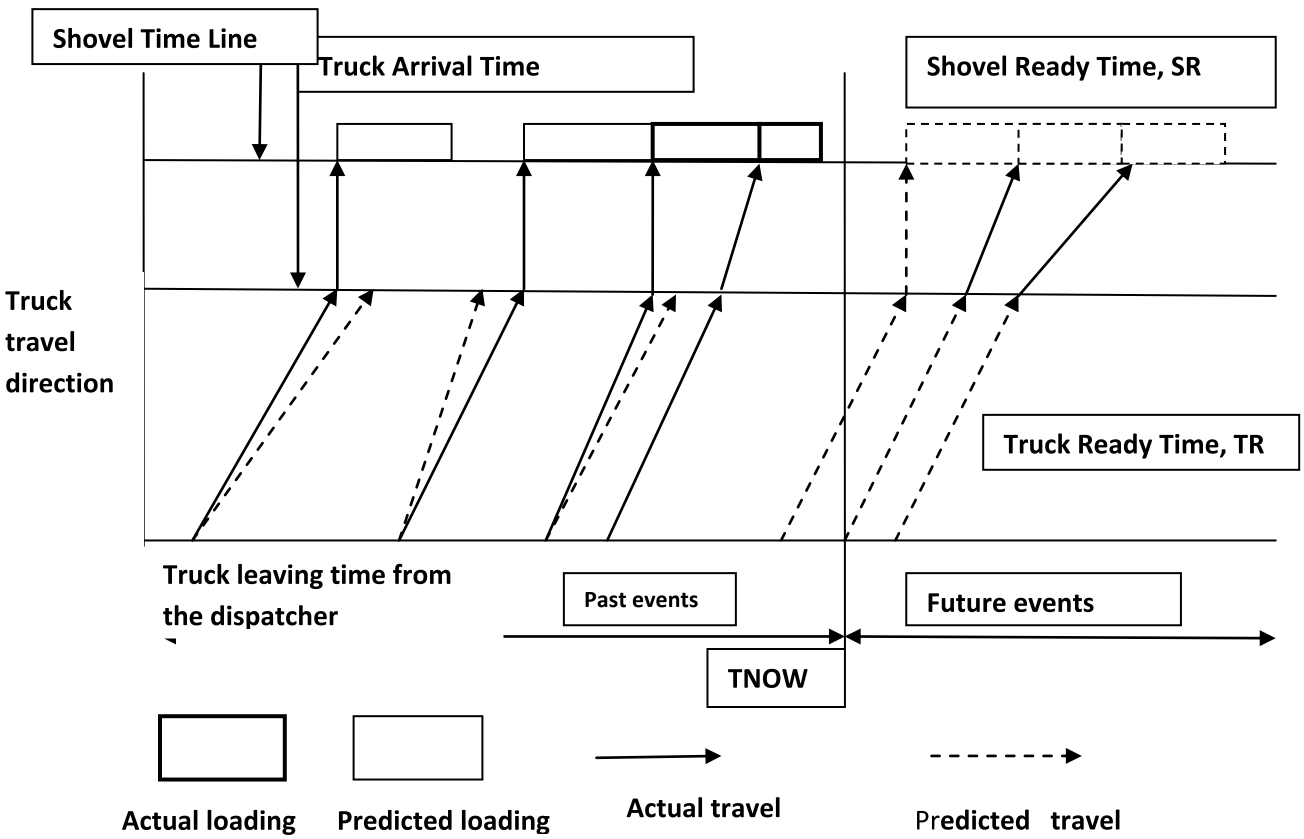

Fig. 3.1 An Example of Shovel Loading Gantt Chart

In this dispatching policy, the dispatcher estimates both the ready times of this truck at the shovels and the ready times of either shovel to commence loading this truck when it reaches independently. The dispatcher then makes a comparison to select the shovel with the least waiting time. After the minimum waiting time is obtained, the truck is assigned and sent to a particular shovel.

Table 3.2 An Example Problem for Minimizing Truck Waiting Time Rule, (MTWT)

No.	Arrival time at the dispatch system TNOW(min)	Travel time to shovel (min)		Time joining travel queue (min)		Waiting Time		Time shovel Is seize		Loading time		Time shovel is released		Shovel ready time		Truck ready time		Difference SR-TR		Max (SR_1-TR_1		Min (SR_1-TR_1	Asigned Shovel no.
		S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2		
1	0	5	6	5	6	-5	-6	5	6	2	3	7	9	0	0	5	5	-5	-6	0	0	0	1or2
2	5	5	6	10	11	-3	-2	10	11	2	3	12	14	7	9	10	11	-3	-2	0	0	0	1or2
3	6	5	6	1	12	1	2	12	14	2	3	14	17	12	14	11	12	1	2	1	2	1	1
4	8	5	6	13	14	1	3	14	17	2	3	16	23	14	17	13	14	1	3	1	3	1	1
5	9	5	6	14	15	2	5	16	20	2	3	18	23	16	20	14	15	2	5	2	5	2	1
6	18	5	6	23	24	-5	-1	23	24	2	3	25	27	18	23	23	24	-5	-1	0	0	0	1or2
7	26	5	6	3	32	-6	-5	31	32	2	3	35	35	25	27	31	32	-6	-5	0	0	0	1or2
8	32	5	6	37	38	-4	-3	37	38	2	3	39	41	33	35	7	8	-4	-3	0	0	0	1or2

3.5 Minimizing Shovel Waiting Time (MSWT)

In this policy, the empty truck at the dispatching point is assigned to the shovel which has been waiting (longest time) for a truck or is expected to be idle next. The objective of this criterion is to maximize the utilization of shovel by minimizing its waiting time. One of the advantages of this criterion is that it tends to balance out shovel productions more evenly and give results closer to objectives. But, this causes a decrease in the overall production because of the long cycle time required to reach the furthest shovel. This policy is recommended in mines having strict grade requirements even tough is does not optimize production. Moreover, it works better in large open-pit mining operations. If the shovels rarely wait for trucks in under-trucked systems, then secondary tiebreaking rules may be necessary to make the dispatching decisions. The decision-making criterion is as follows:

k: arg $\min_i \{TR_i - SR_i\}$, (3.3)

where

k: shovel number to which the truck is assigned

$SR_{i:}$ Ready time of shovel for loading this truck

TR_i: Ready time for the truck to be loaded by the shovel

It must be pointed out that the travel time to each shovel site is not considered in this dispatching policy. Also, it should be noted that if (TR_i - SR_i) is greater than zero, it corresponds to the shovel waiting time for this truck. The same two shovel example problem is given in Table 3.3.

Table 3.3 An Example Problem for Minimizing Shovel Waiting Time Rule, (MSWT)

No.	Arrival time at the dispatch system TNOW(min)	Travel time to shovel (min)		Time joining travel queue (min)		Waiting Time		Time shovel Is seize		Loading time		Time shovel is released		Shovel ready time		Truck ready time		Difference SR-TR		Min (SR_1-TR_1	Asigned Shovel no.
		S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2		
1	0	5	6	5	6	-5	-6	5	6	2	3	7	9	0	0	5	5	-5	-6	5	1
2	5	5	6	10	11	-3	-2	10	11	2	3	12	14	7	9	10	11	-3	-2	-2	2
3	6	5	6	1	12	1	2	12	14	2	3	14	17	12	14	11	12	1	2	-2	1or2
4	8	5	6	13	14	1	3	14	17	2	3	16	23	14	17	13	14	1	3	-3	1or2
5	9	5	6	14	15	2	5	16	20	2	3	18	23	16	20	14	15	2	5	5	1or2
6	18	5	6	23	24	-5	-1	23	24	2	3	25	27	18	23	23	24	-5	-1	0	2
7	26	5	6	3	32	-6	-5	31	32	2	3	35	35	25	27	31	32	-6	-5	0	2
8	32	5	6	37	38	-4	-3	37	38	2	3	39	41	33	35	7	8	-4	-3	0	2
9	33	5	6	38	39	1	2	39	41	2	3	41	44	39	41	38	39	-1	-2	2	1or2

3.6 Minimizing Truck Cycle Time (MTCT)

In this criterion, the empty truck at the dispatching point is assigned to the shovel which will provide the minimum value for the expected truck cycle time for this truck. The objective of this criterion is to maximize the number of truck cycles during the shift. The truck cycle time (TCT) is a function of mean travel time from dumping point to the shovel to be assigned, waiting time at the shovel after truck's arrival, mean loading time required by the shovel, mean travel time from shovel to the dump point, and the mean truck dumping time.

The decision-making criterion is as follows:

$$k: \arg\min_i \{ TCT_i \}, \qquad (3.4)$$

where

k: shovel number to which the truck is assigned

TCT_i: truck cycle time for shovel i.

Clearly, this criterion is strongly affected by the value of the truck cycle time and the overall resulting effect is that more trucks are assigned to the shovels closer to dispatching point. The solution to the same two shovel example is given in Table 3.4. Here, it must be mentioned that the expected truck waiting times are arbitrarily assumed to have the values provided in Table 3.4. But, they are estimated from respective shovel Gantt charts in simulation program.

Table 3.4 An Example Problem for Minimizing Truck Cycle Time Rule,

No.	Arrival time at the dispatch system TNOW(min)	Travel time to shovel (min)		Time joining travel queue (min)		Waiting Time		Time shovel Is seize		Loading time		Time shovel is released		Shovel ready time		Truck ready time		Difference SR-TR		Min (SR_1-TR_1	Asigned Shovel no.
		S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2		
1	0	5	6	5	6	-5	-6	5	6	2	3	7	9	0	0	5	5	-5	-6	5	1
2	5	5	6	10	11	-3	-2	10	11	2	3	12	14	7	9	10	11	-3	-2	-2	2
3	6	5	6	1	12	1	2	12	14	2	3	14	17	12	14	11	12	1	2	-2	1or2
4	8	5	6	13	14	1	3	14	17	2	3	16	23	14	17	13	14	1	3	-3	1or2
5	9	5	6	14	15	2	5	16	20	2	3	18	23	16	20	14	15	2	5	5	1or2
6	18	5	6	23	24	-5	-1	23	24	2	3	25	27	18	23	23	24	-5	-1	0	2
7	26	5	6	3	32	-6	-5	31	32	2	3	35	35	25	27	31	32	-6	-5	0	2
8	32	5	6	37	38	-4	-3	37	38	2	3	39	41	33	35	7	8	-4	-3	0	2
9	33	5	6	38	39	1	2	39	41	2	3	41	44	39	41	38	39	-1	-2	2	1or2

3.7 Minimizing Shovel Saturation or Coverage (MSC)

In this criterion, the empty truck at the dispatching point is assigned to the shovel which has the least degree of saturation among the available shovels. The objective of this rule is to assign the trucks to the shovels at equal time intervals to keep a shovel operating without waiting for trucks. The degree of saturation is defined as the ratio between the number of trucks that have been assigned and the desired number of trucks that should have been assigned to the shovel under consideration. The desired number, also referred to as the saturation number, is the number of trucks given by the ratio of the average travel time for the truck from the dispatching point to the shovel to the average shovel loading time for the truck. The decision-making criterion is as follows:

k: arg $\min_i\{(SR_i - TNOW) / TT_i \}$, (3.5)

where

k: Shovel number to which the truck is assigned

SR_i: Ready time of shovel for loading this truck

TNOW: Time elapsed from the start of shift

TT_i: Mean travel time from dispatching point to the shovel to be assigned.

This dispatching criterion attempts to utilize all the shovels in the system evenly and at the same time, keeps a balance between the truck requirements. This dispatching policy would be desirable in mines with a relatively sufficient number of available trucks to meet the shovel requirements. The same two shovel example problem is given in Table 3.5.

3.8 Earliest Loading Shovel (ELS)

In this criterion, the empty truck at the dispatching point is assigned to the shovel where it is expected to be loaded at the earliest future point in time. This rule tends to reduce truck idle time and prevent long waiting lines. It might result in unbalanced production among the shovels since it encourages dispatching trucks to closer shovels. This might occur seriously if the system is under-trucked. The solution to the example problem is given in Table 3.6.

The decision-making criterion is as follows:

k: arg $\min_i \{\max\{ TR_i, S_{Ri} \}\}$ (3.6)

where

k: shovel number to which the truck is assigned

SR_i: Ready time of shovel for loading this truck

TR_i: Ready time for the truck to be loaded by the shovel

In this dispatching criterion, the distances between the dispatching point and the shovels have significant effect over the dispatching results.

Table 3.5 An Example Problem for Minimizing Shovel Coverage Rule, (MSC)

No	Arrival time at the dispatch system TNOW(min)	Travel time to shovel TTi (min)		Loading time LTi (min)		Truck return time RTi (min)		Expected truck waiting time WTi (min) (assumed)		Truck cycle time TCTi=TTi+LTi+RTi+WTi		Min TCT (min)	Assigned shovel number
		Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2		
1	0	5	6	2	3	6	7	3	0	16	15	15	2
2	5	5	6	2	3	6	7	2	1	15	16	15	1
3	6	5	6	2	3	6	7	1	2	14	17	14	1
4	8	5	6	2	3	6	7	4	1	17	16	16	2
5	9	5	6	2	3	6	7	5	2	18	17	17	2
6	18	5	6	2	3	6	7	4	2	17	17	17	1or2
7	26	5	6	2	3	6	7	2	3	15	18	15	1
8	32	5	6	2	3	6	7	0	2	13	17	13	1
9	33	5	6	2	3	6	7	1	3	14	18	14	1

3.9 Longest Waiting Shovel (LWS)

In this criterion, the empty truck at the dispatching point is assigned to the shovel which has been waiting for a truck longest. The objective of this policy is to balance the production among the shovels.

The decision-making criterion is as follows:

k: arg max {$\max_i$ {$TR_i - SR_i$}, 0}}, (3.7)

where

k: Shovel number to which the truck is assigned

SR_i: Ready time of shovel for loading this truck

TR_i: Ready time for the truck to be loaded by the shovel

Table 3.6 An Example Problem for Earliest Loading Shovel Rule, (ELS)

No	Arrival Time at Dispatch Point, TNOW, (min)	Travel Time to Shovel, (min)		Time Joining Shovel Queue		Waiting Time (min)		Time Shovel is Seized		Loading Time (min)		Time Shovel is Released		Shovel Ready Time, SR_i		Truck Ready Time, TR_i		Max {TR_i, SR_i}		Min{ max{TR_i, SR_i}}	Assigned Shovel Number, k
		Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2		
1	0	5	6	5	6	-5	-6	5	6	2	3	7	9	0	0	5	6	5	6	5	1
2	5	5	6	10	11	-3	-2	10	11	2	3	12	14	7	9	10	11	10	11	10	1
3	6	5	6	11	12	1	2	12	14	2	3	14	17	12	14	11	12	12	14	12	1
4	8	5	6	13	14	1	3	14	17	2	3	16	20	14	17	13	14	14	17	14	1
5	9	5	6	14	15	2	5	16	20	2	3	18	23	16	20	14	15	16	20	16	1
6	18	5	6	23	24	-5	-1	23	24	2	3	25	27	18	23	23	24	23	24	23	1
7	26	5	6	31	32	-6	-5	31	32	2	3	33	35	25	27	31	32	31	32	31	1
8	32	5	6	37	38	-4	-3	37	38	2	3	39	41	33	35	37	38	37	38	37	1
9	33	5	6	38	39	1	2	39	41	2	3	41	44	39	41	38	39	39	41	39	1

3.10 Adaptive Rule (AR)

In this study, a general combined truck dispatching criterion is developed following the comprehensive analysis and comparison of various basic dispatching criteria presented above. The combined criterion, also called as adaptive rule, applies a procedure to dispatch the trucks at the dispatching point by utilizing the standardized utilization of both shovels and trucks. The standardized truck utilization is defined as the ratio of the difference between the current truck utilization and the mean truck utilization divided by the standard deviation of truck utilization. Similarly, the standardized shovel utilization is defined as the ratio of the difference between the current shovel utilization and the mean shovel utilization divided by the standard deviation of shovel utilization. That is;

$$STU = \frac{TU_{cur} - TU_{mean}}{SDTU}, \qquad (3.8)$$

STU: Standardized truck utilization

TUcur: Current truck utilization

TUmean: Mean truck utilization

SDTU: Standard deviation of truck utilization

and

$$SSU = \frac{SU_{cur} - SU_{mean}}{SDSU}, \qquad (3.9)$$

where

SSU: Standardized shovel utilization

SUcur: Current shovel utilization

SUmean: Mean shovel utilization

SDSU: Standard deviation of shovel utilization

This adaptive rule tries to achieve a balance between two dynamic system performance measures, (i.e. truck utilization and shovel utilization). The decision making criterion selects one of the two basic dispatching rules that have the best performances for the given performance measures. The two best performing basic rules are selected from among the eight basic heuristic policies mentioned above by using the results of statistical analysis of simulation experiments.

CHAPTER IV

DISPATCHING ALGORITHM

4.1 Introduction

This chapter deals with a detailed description of the input data set components, basic modeling assumptions made and the general structure of the simulation program. The input data are one of the most important aspects in the implementation of any simulation study. The modeling of open pit haulage systems using computer simulation has been in widespread use for many years.

The models have been developed in a variety of ways including time study data, calculation based on manufacturers' performance curves and real time data generated by computerized truck dispatching systems.

In the time study approach, the individual times of various movements and operations are recorded. For example, the time it takes a certain type of haulage unit to traverse a haul road segment is measured directly by an observer in the field. Travel times for each truck type, both loaded and empty, are required for each road segment. Similarly, loading and dumping times are required for each truck type for various shovels and dump points. During simulation process, trucks are cycled through the haulage network following a series of dispatching rules regarding shovel assignment. When a truck enters a road segment, it is randomly assigned a travel time based on the time study data. This is known as Monte Carlo simulation because of the random way the data is selected. The procedure is simple and the simulation process moves trucks through a network according the underlying rules selected. A computer simulation program performs these tasks quickly and keeps track of the required output statistics. However, time study based simulation has several major disadvantages relating to the conditions and the configurations of the haulage road network. These studies are useful when selecting equipment for a new mine. The configuration of the haulage road network change frequently and maintaining current data are time consuming and impractical if the data are collected manually. Estimating travel times through a calculation procedure is preferable in these cases. Modern computer dispatch systems keep continuous track of vehicle movements and create a real time computer database of haulage fleet movements. This could provide a powerful method of updating the model based on current shovel locations, road conditions, etc.

In developing a computerized truck dispatching model, it is necessary to acquire detailed information related to the haulage system. An accurate assessment of the actual working of the haulage system and the sequence of events are essential. All these data project a finite picture of the exact problem involved and this gives an idea of the components that need to be simulated.

The technique of simulation characterizes the system in terms of its components and a set of rules relating the interactions between these components. Hence, the model is defined by this set of rules and the components, namely trucks and shovels, each with its own characteristics.
The program developed in this study is designed with the objective of studying the effects on productivity by continuously dispatching trucks in medium-sized open pit mine under various heuristic policies. Although the simulation program is developed primarily to test the dispatching procedures, several problems related to an open pit mine operation can also be solved. Prior to making a large capital expenditure for loading and haulage equipment, there is an evident need for careful evaluation of possible combination of shovels and trucks and haul road configurations in the light of planned production requirements in order to achieve minimum production cost. Hence, it is possible to determine the equipment requirements according to the productivity obtained with each shovel/truck combination, evaluation of equipment replacements and testing different haulage layouts in order to determine best possible haulage network.

The model developed should be simple to use but, at the same time should adequately duplicate the real operations to be credible. The economic feasibility of using a truck dispatching system in an open pit operation is also very crucial. The selection of dispatching policies is done according to the objectives of a particular operation, which may change with time. The mine management should decide which dispatching procedure is to be used in a specific mine. For example, minimizing truck waiting time rule (also called maximizing truck use) yields consistently higher fleet production. But, it may not be useful when the operation requires grade control or when the differences in truck travel times between shovels is large. In general, it is more desirable to have all the operating shovels working at the same rate (i.e. utilization). The success of a dispatching procedure depends to a great extend upon the number of truck operating in the total range from under-trucked to over-trucked situations. The major purpose of providing a dispatching system is to maximize productivity of the system. This can be done through procedure such as maximizing either truck or shovels utilizations.

4.2 Basic Assumptions

The following basic modeling assumptions are made in the program for the open pit truck/shovel haulage system developed in this study.

1. All trucks in the mine are the identical (i.e. their capacity, motor power, speed, etc are the same).
2. All shovels in the mine are identical in terms of their loading capabilities
3. More than one truck can travel along different roads (i.e. trucks are allowed to overtake each other along the haul roads).

4. All shovels and the dumping site can serve only one truck at a time and trucks may form queues at the dumping point.

6. Single material type is assumed for the simulation program and all trucks in the mine dump their loads at the same dumping site.

7. All trucks start operation at the parking area near the dumping point at the start of the shift and park there at the end of each shift.

8. During a program run, the haulage system is performing without any rest (i.e. eight hours per shift).

9. In modeling the breakdowns of trucks, all trucks are only checked out for failure after dumping their loads at the dumping area during a shift.

10. In modeling the breakdown of shovels, all trucks that are previously dispatched to a shovel which is in failure mode remain in the same circuit until it is replaced by a standby shovel and it is further assumed that there is a sufficient supply of standby units available at the mine. Furthermore, trucks are not dispatched to this shovel location until it is replaced by another shovel.

4.3. Input Data

When performing a stochastic simulation study, the sources of randomness for the system under consideration must be represented properly. In many simulation studies, little attention has been paid to the process of selecting input probability distributions. In a simulation study such as the analysis of truck dispatching criteria, proper modeling of individual events is crucial to obtain meaningful results. Since random samples from input probability distributions drive a simulation model of a real system through time, basic simulation output data or an estimated performance measure computed from them are also random. Therefore, it is important to model system randomness correctly with appropriate probability distributions. It must be emphasized that the technique of simulation is the most practical method used for producing experimental data necessary for conducting different operating policies in open-pit mines.

One of the most important aspects of any simulation model is the reliability of the results produced. This is a function of the accuracy of input data collected. Thus, the importance of time studies to be carried out must be realized in order to decide on how much of the real system must be represented in the model. The best simulator is only as good as the input data it receives. The input data are very difficult to generalize in order for the model to be universally applicable. Every mine is different in truck fleet size and type, shovel size and type, number of crushers and dumps, configuration of haulage networks, etc. Most mines operate with multiple types of shovels and trucks and with different operational policies so that it is impossible to define a general input data set for the simulation model. In time study operations, it is very important to clearly define the duration of each event component and ensure that the definition of the events are the same no matter who conducts the time study. Basically, the truck/shovel operations are observed through the following six event components:

1. Truck loading (time): it is the total time it takes to load a truck. This time starts at the moment the shovel starts digging and ends when the shovel operator gives a signal indicating the completion of the loading activity.
2. Spotting (time) at the shovel: this time starts from the moment the truck leaves its queue position and moves towards the shovel to the moment it achieves the position for loading.
3. Spotting (time) at dump: this time starts from the moment the truck begins motion from its queue position towards the dump to the moment it achieves the position for dumping.
4. Dumping (time): the dumping time starts from the moment a truck initiates unloading to the moment the truck begins to move away from the berm after dumping its load.
5. Truck full travel (time): it starts at the time the shovel operator gives a signal and ends when the truck reaches the dump point or starts to wait in the queue at the dump.
6. Truck empty travel (time): this time starts at the end of the dumping operation and ends when the truck reaches the shovel or starts waiting in the queue in front of the shovel.

All data collected from time studies for the truck/shovel systems should be nonnegative, that is, the values must be greater than zero. In this study, the spotting (time) at shovels is included in the waiting time at the shovel, and the spotting (time) at dump is included in the waiting time at the dump point if the truck has to wait or in the truck full travel (time) if the truck is immediately served by the shovels. The input data to be used in the programs are not taken from a real open pit mine. Instead, it is taken from literature values that are most commonly used. That is, the simulation model is developed for a hypothetical open pit mine.

4.4 Algorithm Structure

Sound modeling complex systems requires a detailed knowledge of both the program language and the system under study. In the execution of a truck dispatching model, the most important part is the simulation of the system. When simulating a truck/shovel operation, it is essential that the method used be precise and reliable. Modeling of truck movement in conjunction with shovel productivity is the most critical aspects of the simulation program. The entire decision-making process is affected by the expected equipment performances. Simulation software should be selected based on how well it is suited to the scope and the level of detail of the specific model to be developed.

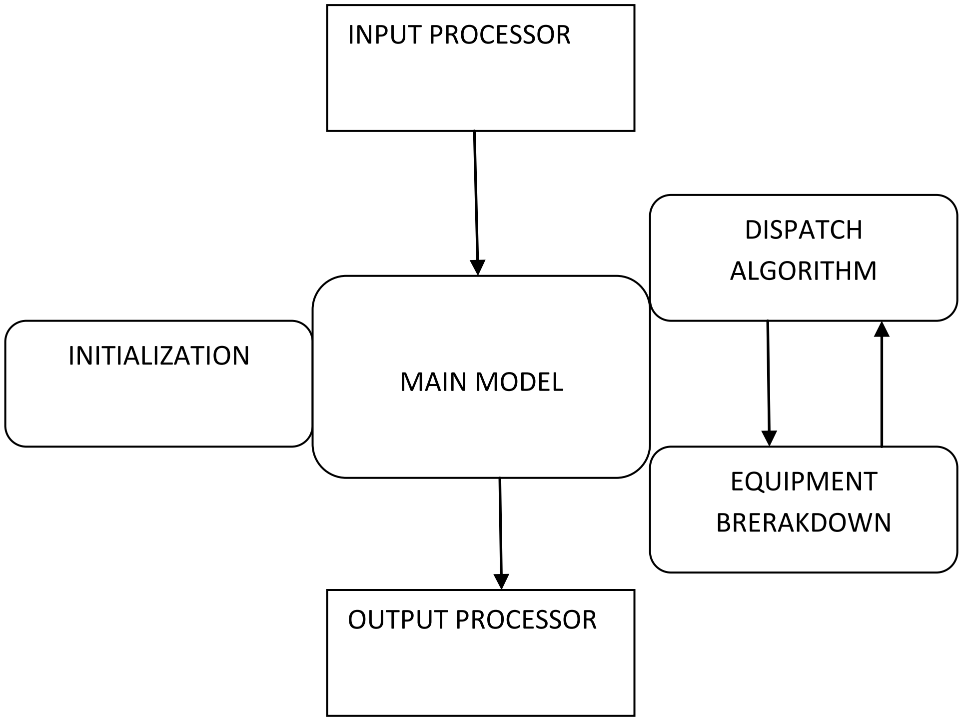

Figure 4.1 General Structure of the Simulation Model

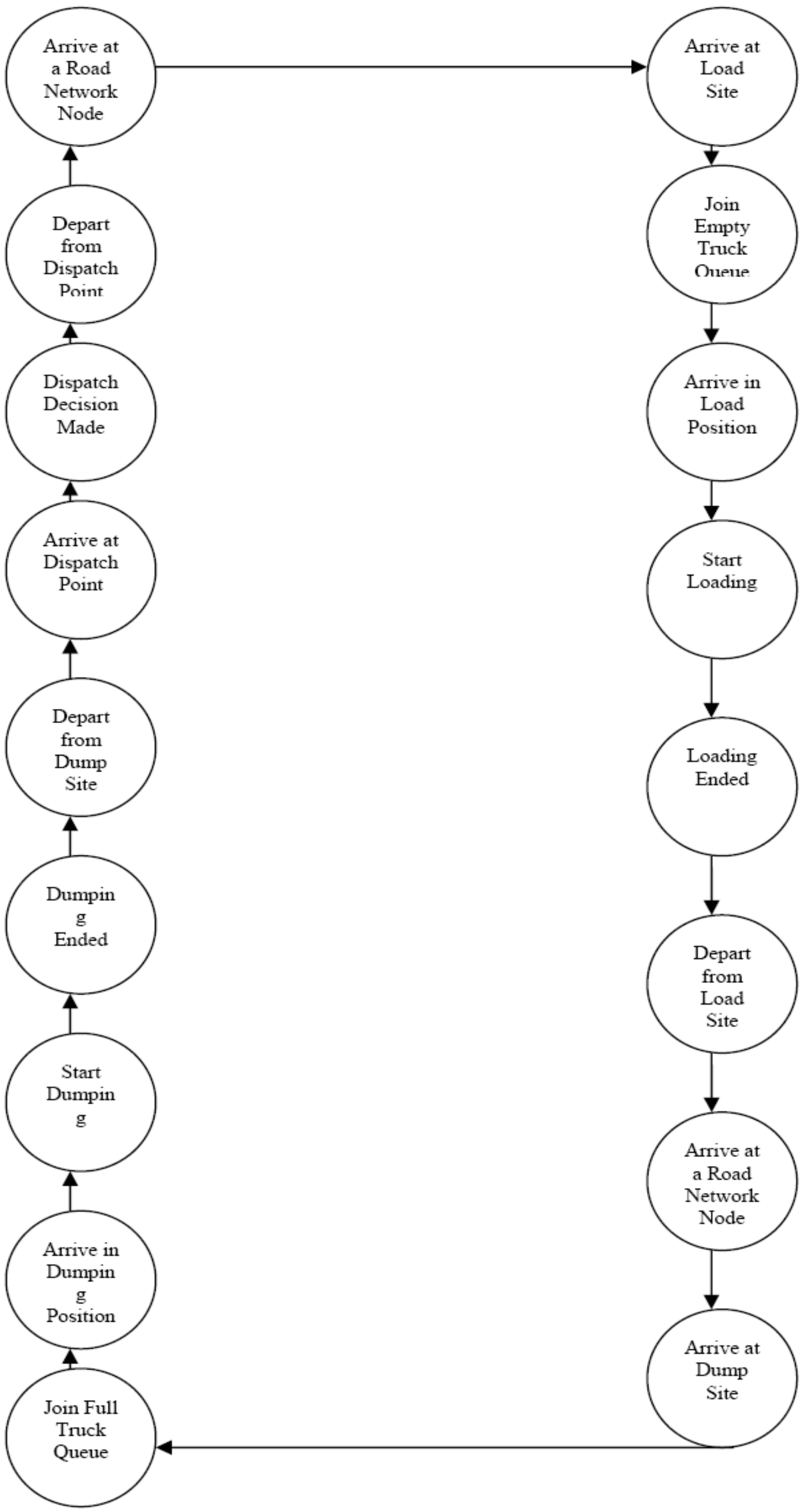

Fig.4.2 Event Sequence for Truck Haulage Model

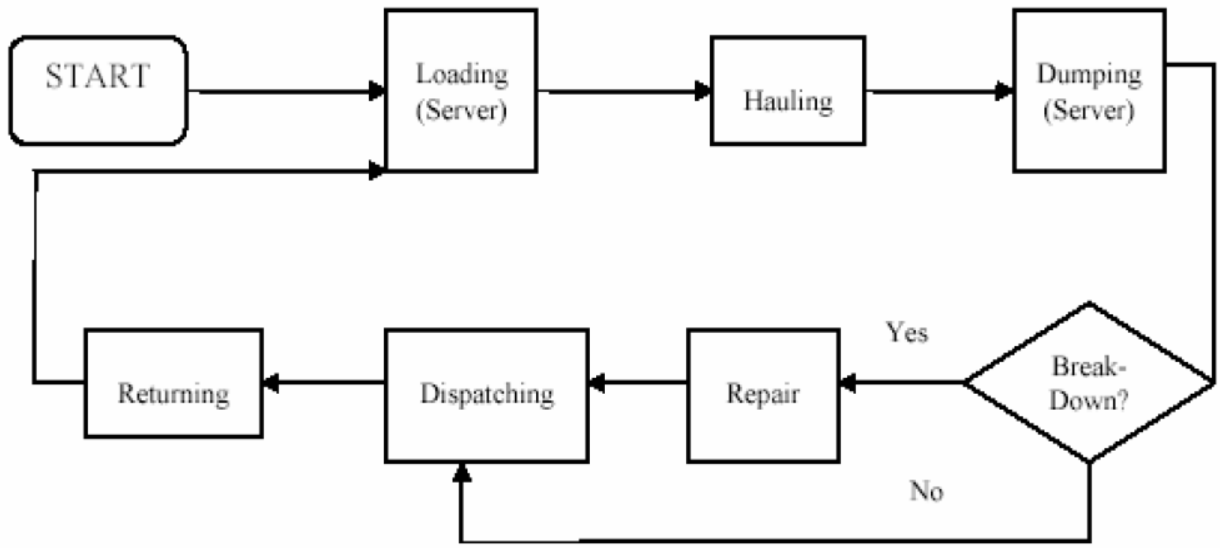

Figure 4.3 Truck-Shovel System Modeling Concepts

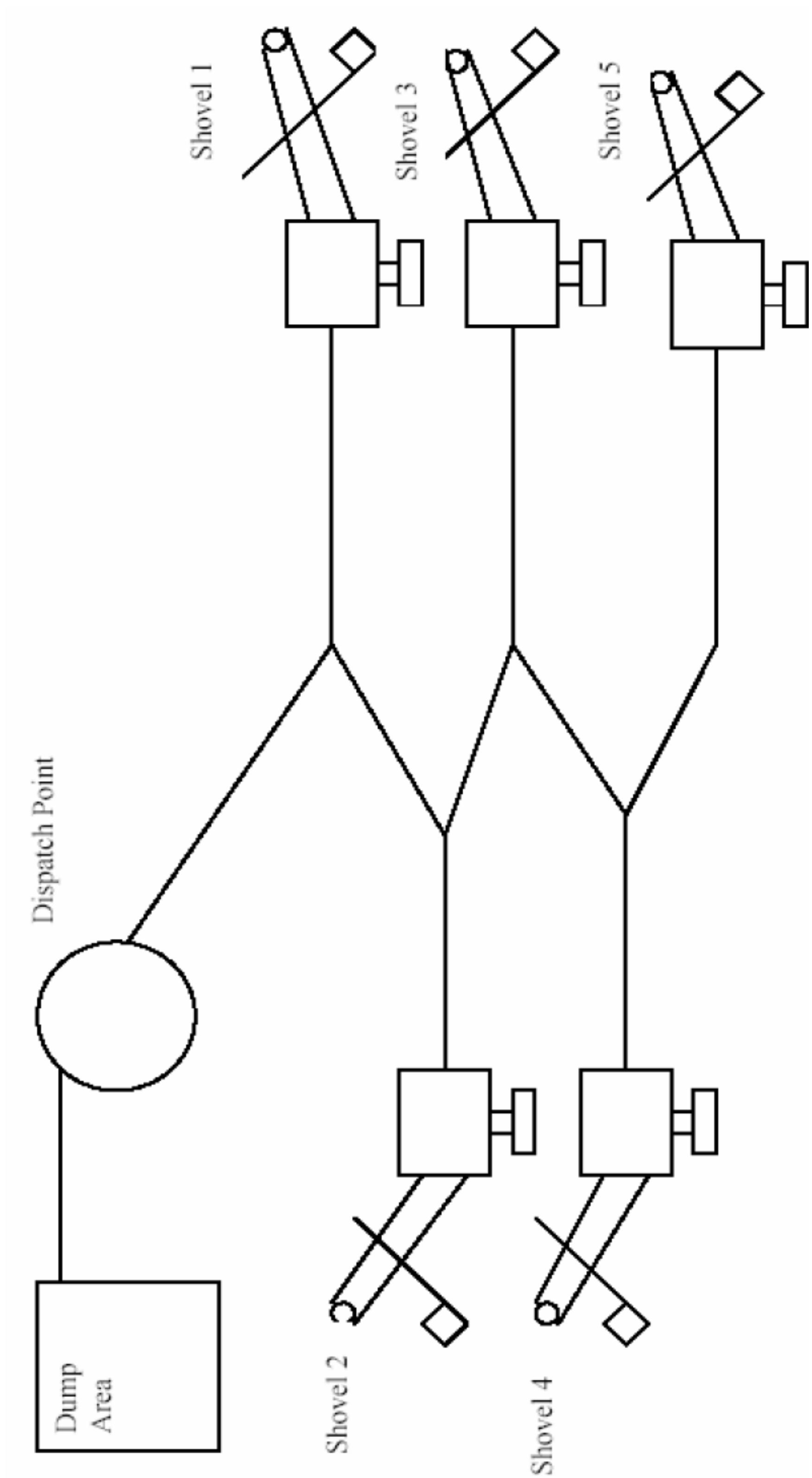

Figure 4.4 A Typical Truck-Shovel Mining System.

Algorithm

Step 1: The program deals with atomization of machines with computers

Step 2: Divide the total machine time into breakdown time, idle time, usage, maintenance

Step 3: We also calculate the availability, utilization, capacity, by keeping track of time by counter

Step 4: If the computer is unable to read or write data the process terminates automatically.

Step 5: The computer reads the data

Step 6: If Current location! =Previous location and Vehicle is at unload point it increments the counter by one

Step 7: If Current locations==Previous location and Vehicle at load point it increment idle counter by one else if Vehicle at unload point then vehicle lies anywhere else and breakdown counter is incremented by one

Step 8: The availability time is calculated as follows: **total time-breakdown-maintain /total time**.

Step 9: The utilization time is calculated as follows: **total time-breakdown-maintain-idle/ total time**

Step 10: Usage=capacity*count

Step 11: Print availability, usage, idle, breakdown time

Step 12: stop

4.5 Real-time dispatching module

It is a real time dispatching computer program. It can manage data for a medium to small size operations. The program is written in java using netbeans 6.0 beta 1.the user interface provides continues visual information on the position and the state of the truck and loading unit and statistics concerning the shovel truck system. The user may choose between different dispatching rule, which is maximizing truck utilization, maximize shovel utilization. Dispatching is implemented on heuristic rules. It dispatches truck on the basis of equipment cycle times, equipment state, production objective and shift time schedules. It uses data provided the PMIS (production management and information system) which is system where all the data gathered by the mobile control unit placed on each equipment are transmitted via a dedicated radio link to personal computer in the operation's control room, where they are manipulated by PMIS. But it can be adapted to communicate with any relational data base management system that provides appropriate interface to the programming.

4.6 User’s windows

The user interface consists of:

- Main
- Truck info
- Loader/shovel info

The main window

The main window is divided into three areas. The left hand side is used to displays shovel-truck system’s statistics (ore production, waste production, total production, loaders utilization, truck utilization) for each shift hour as well as truck and loader fleet status.

In the central area, the control buttons which are used to open other windows. The right hand side area is used to visually display the state and relative position of each truck within the system, and the state of each loading unit. This window is updated data set by the user time interval.

4.7 Working structure

When a truck enters the system, or, after dumping its load, returns to the loading areas, it travels to the dispatching decision point. The developed program calculates the expected travel time of this truck from the decision point to each loading unit, and the expected time for each loader to serve all the trucks already assigned to it (i.e. the truck being loaded, truck waiting to load, truck travelling to this loader). The module assign the truck to a specific loader on the basis of the two above entities for all possible combination, plus the priorities set by the user and the applied dispatching procedures. Crossing the decision point the assignment is displayed on the truck’s MCU screen. At any moment the display provides the dispatcher with the ability to override the assignment automatically given to the truck by the module and directs this truck to other destination.

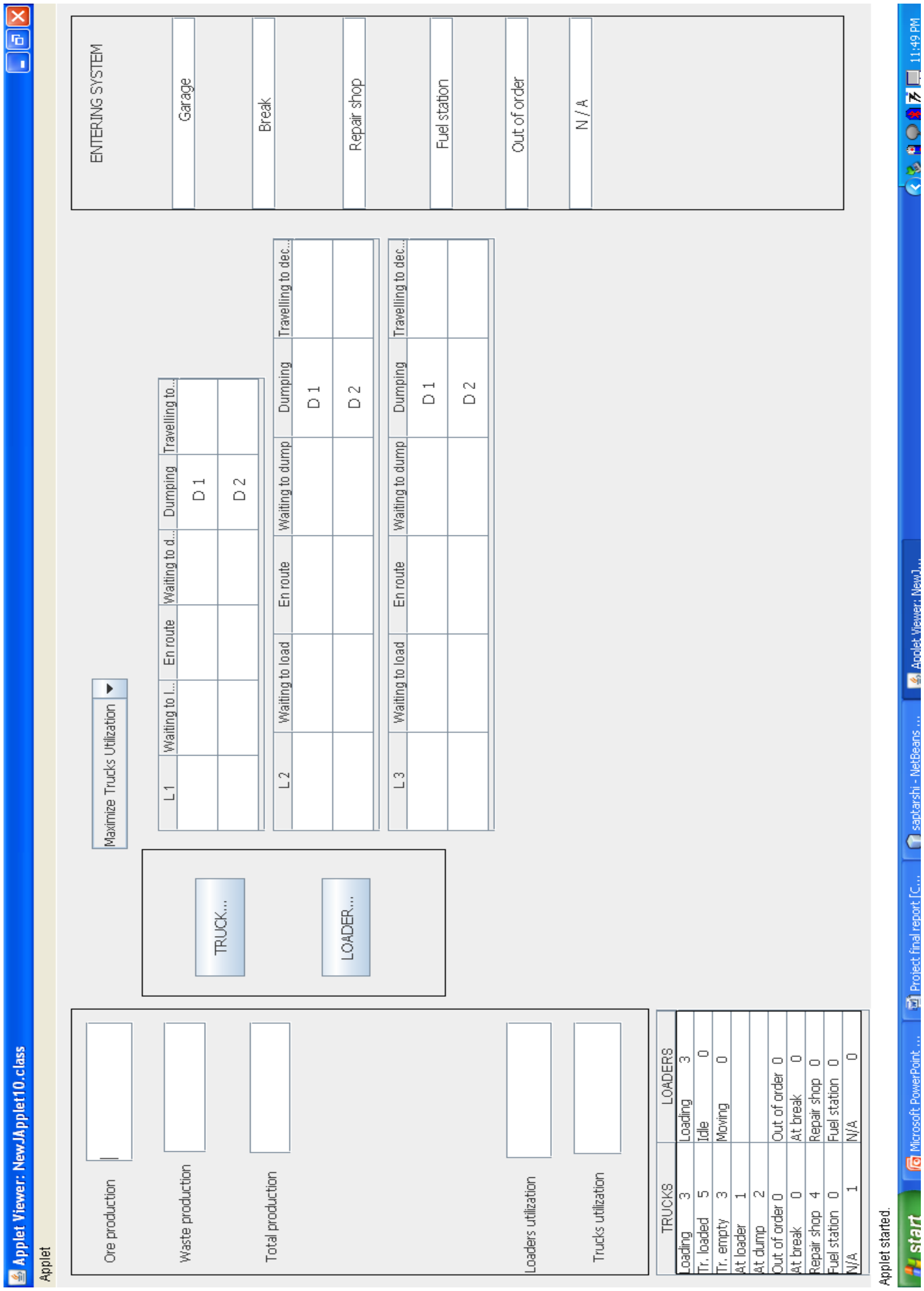

Figure 4.5 Main window

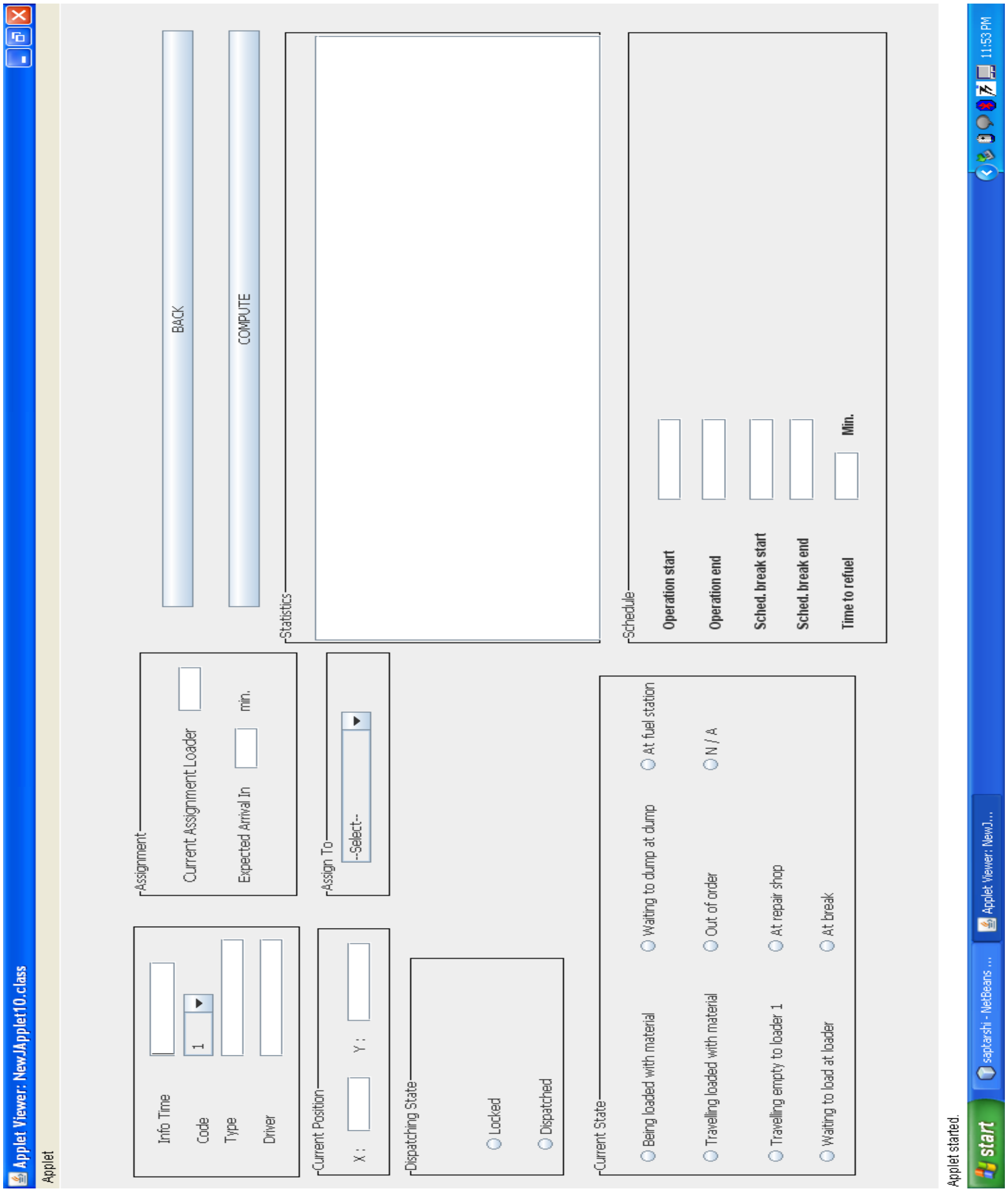

Figure 4.6 Truck info window.

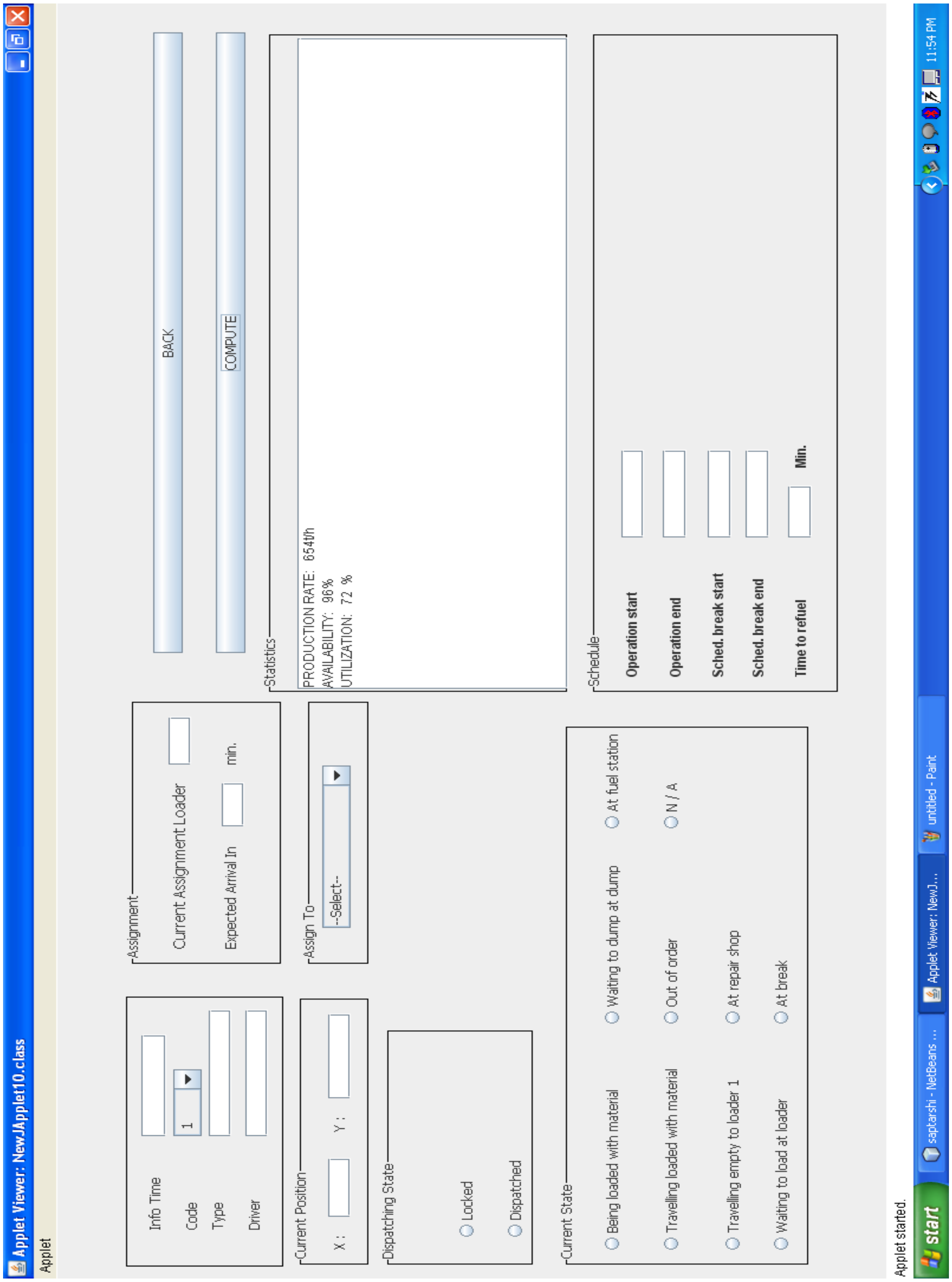

Figure 4.7 Compute window

CHAPTER V

GENERAL CRITERIA FOR COMPUTER BASED DISPATCH SYSTEM

5.1 Advantages of the computer system

Performance of the system:

- **Modularity**: A complex system may be divided into simpler pieces called modules. A system that is composed of modules is called modular. There are many advantages to divide the system into modules. Modules are easy to handle in terms of error handling or debugging, testing etc.
- **Anticipation of change**: The software undergoes changes constantly. Changes are due both to the need for supporting evolution of the application as new requirements arise or old requirements changes.
- **Separation of concerns**: - Separation of concern allows us to deal with different individual aspects of a problem, so that we can concentrate on each separately. More over the equipments division are also divided into different type of equipments such as
- Dumpers, Dozers, Shovels, Drills, etc.
- **Incrementality**: This is the concern with the software quality. Instrumentality characterized a process that proceeds in stepwise fashion, in increments. The desired goal is reached by successively closer approximation to it. Each approximation is reached by increment of previous one.
- **Speed of use**: The speed of use of user interface is determined by the amount of time and effort required on the part of the user to initiate and execute different commands. It is moreover simple to use.
- **Error rate**:-A good user interface allows minimizing the scope of committing error while initiating different commands. As because all the instructions are given step by step clearly, there is very less chance of committing errors during the execution of the program.

5.2 Software quality: A quality product is defined in terms of its fitness purpose. Software is said to be qualitative, if it will perform as per the system requirement specification. It has the following features from quality point of view.

- **Portability**: A software product is said to be portable if it can easily made to work in different operating system environments in different machines. With other software product etc.

- **Usability**: A software product has a good usability if different categories of user can easily invoke functions of the product.
- **Reusability**: A software product has rood reusability if different modules of the product can be reused.
- **Maintainability**: A software product is maintainable, if errors can be easily corrected as when they show up, if new functions are added to the product and if the functionalities of the product can be easily be modified. Very good comment lines have been incorporated in the program for easy error detection and rectification is very easy.

5.3 Hardware and software requirement of the computer based system

The computer system where the system has been developed has the following hardware features:

1. Hard disc: 40 GB
2. Pentium III processor
3. 128 MB RAM (Minimum)
4. Floppy drive 1.44 MB and CD ROM

Operating system: Window 98/windows Xp

Language used: java (Net beans 6.0 beta 1), SQL, Microsoft Access for data base management.

Netbens 6.0 beta uses java platform which is easy and simple to use. Basically the visual interface makes it easy for user to develop such a program. Easily accessible command box and readily usable commands makes work simple.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

In this dissertation, computer algorithm were developed using Netbeans 6.0 beta 1 software using java as the platform and SQL and a language for data base management for a hypothetical medium-sized open pit mine consisting of several production faces and a single dump location. Truck dispatching systems were examined and it was found that they offered the potential for improving the performances of open pit haulage systems. Truck dispatching issue in open-pit mines took place in a dynamic environment with performance being a function of competing parameters. Heuristic approach was considered as the most appropriate technique to assess the dispatching policies due to the variability of the interdependent components of truck/shovel operations. The validation of computer models was done by the interactive debugging facility of the PROOF Animation Software. In this study, eight basic heuristic dispatching policies were modeled to test the effects of dispatching rules. Also, an adaptive rule was developed using the standardized utilizations of shovel and trucks resources.

The dispatching algorithms based on heuristic rules provided the simplest approach to computer-based truck dispatching problem. They were also easier to implement and did not require much computations when making the dispatching decisions in real-time. Therefore, they could also be implemented in very large and complex mining operations. Heuristics-based dispatching could bring about improvement in production by reducing waiting times of equipment resources. The under-trucked or over-trucked status of the systems would play a critical role in determining the usefulness various heuristics. The benefits of dispatching would be more in the case of complex haulage networks due to the high interference between systems components. Computer simulation experiments were made to investigate the effects of several decision factors likely to affect the performance of these systems. These factor were as follows: the dispatching rules applied, the number of trucks operating, the number of shovels operating, the variability in truck loading, hauling and return times, the distance between the shovels and the dump site, and the availability of shovel and truck resources. Three performance measures selected were the total truck productions (i.e. truckloads), overall shovel utilization, and overall truck utilization. Also, the effect of truck cycle time components (i.e. loading, hauling, and return) was not significant, either. However, the main factors affecting the three performances were the number of truck operating (i.e. under-trucked or over-trucked status of system), the number of shovels operating, the distance between the shovels and the dumping site, and the availability of shovel and truck resources. There were also significant interaction effects between. Finally, the following conclusions were made:

a) The dispatching criteria values should be calculated as a function of the present status of the system, thus there is no extra data requirement.

b) The existing heuristic rules were very weak in trying to simultaneously attain multiple performance goals such as productivity and utilization.

c) By their very nature, these rules would provide truck assignment to the shovels only in a one-truck-at-a-time. Hence, myopic decisions are made.

d) The current truck at the dispatching station was dispatched to the shovel where it contributed the most. However, the global optimal decision should consider all trucks all times that are expected to request dispatching decisions in the near future.

e) Each mine was very unique and, therefore, should evaluate each policy separately according to its objectives. Implementing a truck dispatching system with a specific dispatching policy could not ensure the desired benefits for all situations.

f) The development of reasonably inexpensive and powerful computer resources together with the increasing programming abilities of software developers would allow a wide choice of dispatching systems to become commercially viable for medium-sized open-pit mines, also.

g) The simulation results confirmed conclusions made by previous researchers such that no basic rule dominates all others under all conditions.

h) The adaptive rule developed improves the system's performances slightly under most of the cases studied.

The following directions are addressed for further research.

- The developed program in this study can be modified to consider the case of variable number of operating shovels to prompt the users for entering the number of shovels as an input parameter.
- More dispatching rules could be developed and statistically compared with the existing nine rules.
- The developed program should be validated in an existing real open-pit mine system.
- Analytical stochastic models for the open-pit haulage systems like queuing networks could be developed
- Data warehouses could be developed for real systems in which the production related data are stored. These data could be analyzed using data mining techniques to assist the decision makers in increasing the productivity as well as utilizations.
- The basic assumptions of single dispatching point, single truck type, single shovel type, single material destination can be relaxed and studied for a complex mine.

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